HITSZ

贸泽电子 MOUSER ELECTRONICS

# 开关电源电磁兼容分析和设计技术
# EMC Analysis and Design Technology of a Switched Mode Power Supply



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08, 16, 2018

# 本资料相应课程可在电子研习社APP上观看，更多精品好课推荐

## 陈为 - 功率变换器磁元件高频化的挑战与对策

- 磁元件高频化带来的理论和实际问题
- 磁芯的高频损耗及特性
- 绕组的高频损耗分析及特性
- 磁性元件的优化设计
- 高频阵列化磁性元件

## 陈桥梁 - 功率半导体器件应用及电源设计

- 常用功率半导体器件的基本原理及特性对比分析
- 功率MOSFET的开关过程分析及EMI整改策略
- 功率MOSFET关键参数解读及选型原则
- 功率MOSFET在电源中的应用案例分析
- 基于几种典型电路仿真软件的电源设计

## 邵革良 - 精通反激电源变压器及电路设计

- 反激电源的类型与特点
- 精通反激电源设计的关键
- 反激电源变压器计算方法
- 反激电源变压器计算实例讲解
- 反激电源变压器的绕线制作技巧

## 徐强华 - 电子产品的电磁兼容设计

- 电磁兼容基础
- 电子产品的电磁兼容性设计
- 电磁兼容测试技术
- 用户现场的EMC问题
- 常见问题及解决方法

## 傅强 - 电子电路基础知识讲座

- 电子电路设计基础知识
- 晶体管电路设计
- 运放应用基础
- 电力MOSFET开关
- 电源管理

## 李义 - 开关电源EMC设计实用技术

- 开关电源电磁兼容特性
- 开关电源EMC接地信号分析
- 线制非隔离系统设计考虑
- 两线制隔离系统设计考虑
- E接地系统设计考虑

## 陈为 - LLC电路磁元件分析及设计技术

- LLC电路的基本工作原理
- LLC电路磁元件的特点
- LLC电路磁元件损耗分析与绕组设计
- LLC电路磁元件的磁集成技术
- LLC电路磁元件的电磁干扰特性

## 黄敏超 - 电磁兼容理论设计与整改实践

- 电磁兼容基本概念
- EMI 电磁干扰法规、理论与整改篇
- EMS 电磁抗干扰法规、理论与整改篇
- EMC设计与整改的展望

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# 内容

和军平

哈尔滨工业大学（深圳）
副教授



## 教育经历：

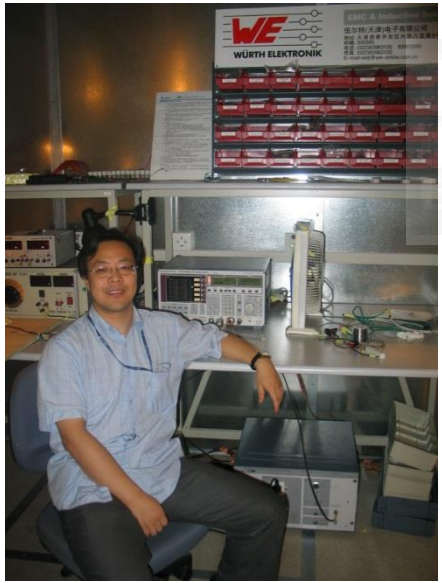
2003年—2005年　博士后（电气工程），清华大学、台达DPEC
1999年—2003年　获博士学位（电气工程），清华大学

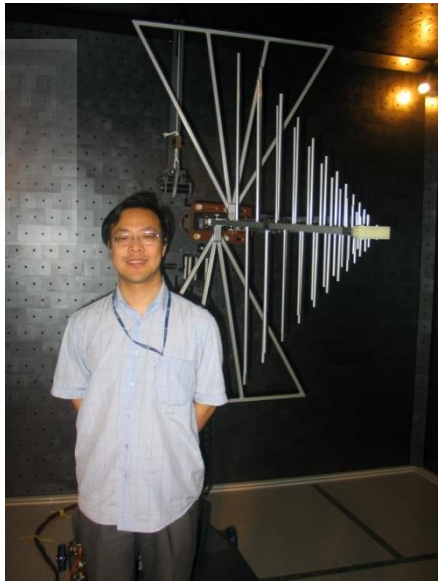
## 研究方向：

电力电子电磁兼容，电力电子技术

# 主要EMC科研项目:

1）国家自然基金资助项目：2项
2）深圳市科技计划：3项
3）企业EMC课题项目：10多项
4）IEEE-EMC、ECCE,PESC，电机工程学报发表论文80多篇、国内外专利7项



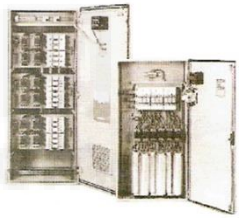



# 第1节：开关电源的电磁兼容设计挑战

开关变换技术功能灵活、效率高、体积小，在国民经济中应用广泛！

新能源逆变发电

电力系统交/直流输调电：



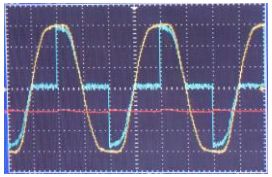
电力传动：电力机车、电动车

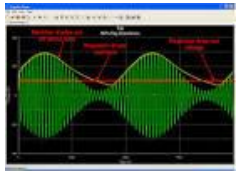
开关电源：UPS、A2D、D2D

# 开关变换也不可避免地产生负面效应

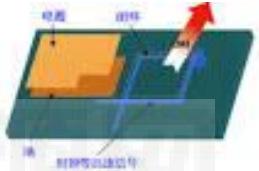


电能质量问题：谐波、电压波动、电压暂降等





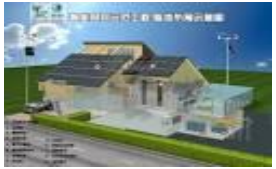
干扰负载及邻近设备：高速信号线、电机轴电流



降低自身稳定可靠性和抗扰性：模/数控制电路

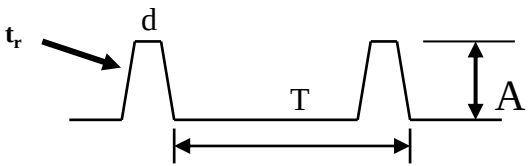
形成无线电干扰：辐射超标

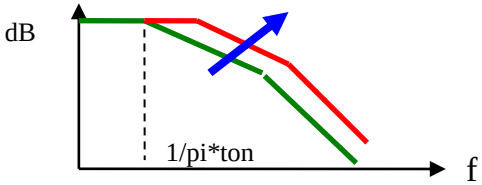
危害电磁环境：家居、汽车内、新能源电场



# 新一代半导体功率器件新性能新速度 SIC/GaN

更高的工作频率、更高的V，i，dv/dt、di/dt，更强高频频谱！

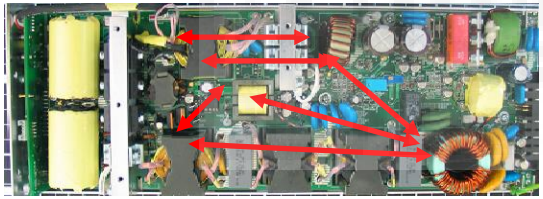


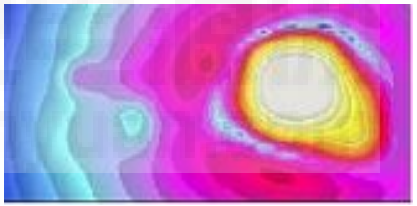




10MHz/1MMz

更强的 EMI 源

更小的体积，更强的电磁耦合，更加复杂电磁干扰形成和传播！





更多互联/串并联开关电子设备，电磁干扰时空随机分布更复杂！

更大的挑战！

# 第2节　开关电源电磁干扰发射的测试

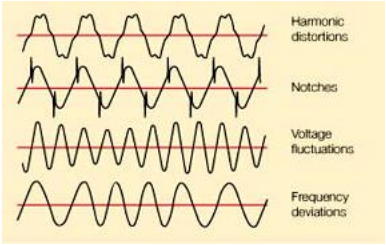
开关电源电磁兼容
- 电源对外界不产生电磁干扰（EMI）
- 能承受一定的外界的电磁干扰　（EMS）

电子产品电磁兼容认证：FCC（美），CCC（中国），CE（欧洲）

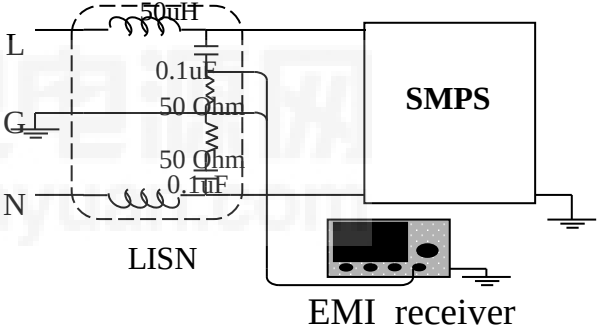
电磁兼容认证测试
- 电磁干扰发射测试（EMI）
  - 低频：电能质量
  - 中频：传导发射
  - 射频：辐射发射
  - ……
- 抗电磁干扰能力测试（EMS）
  - 时域测试：雷击、静电
  - 频域测试：射频干扰
  - ……

# 干扰的频率范围分为低频、传导频段、辐射频段

谐波（Low frequency，50Hz及其谐波）



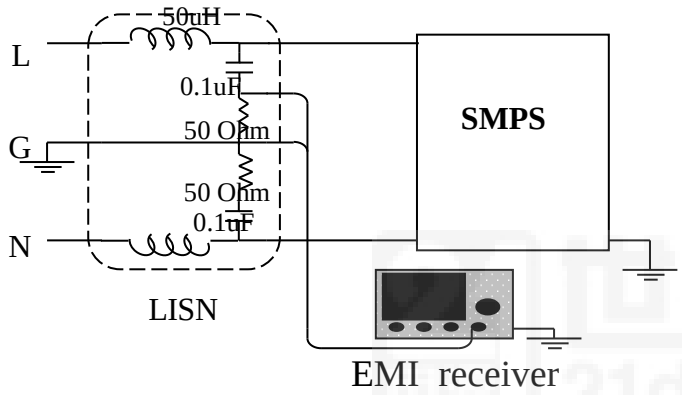

传导（middle frequency，9k-30MHz）




感应和辐射（Middle-Radiated frequency）

# 传导干扰发射测试

## 测试原理和布局

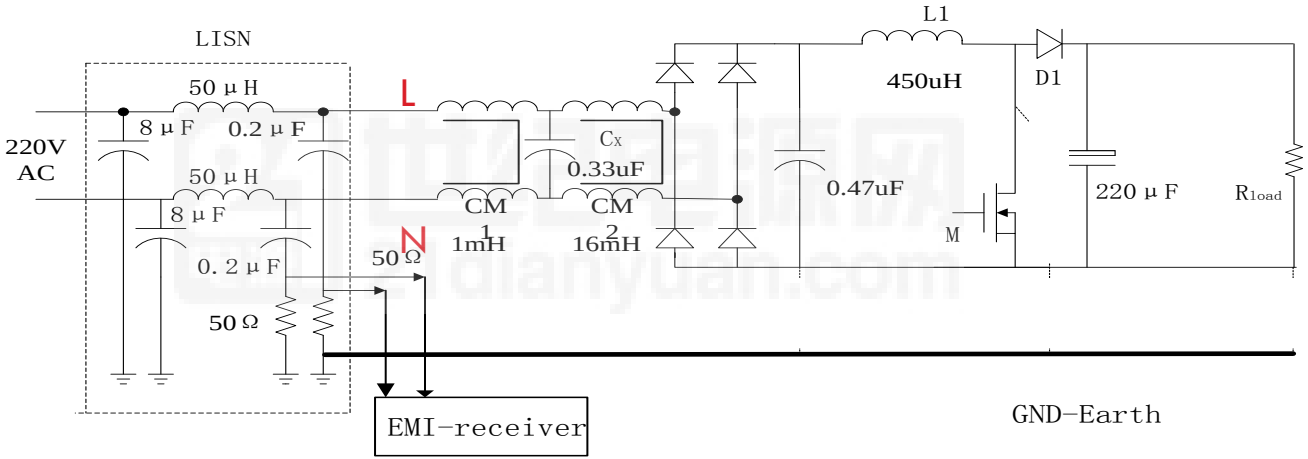



主要设备

- LISN：线路阻抗稳定网络
- EUT: 被测设备
- GND: 金属地平面
- EMI receiver: 电磁噪声接收机

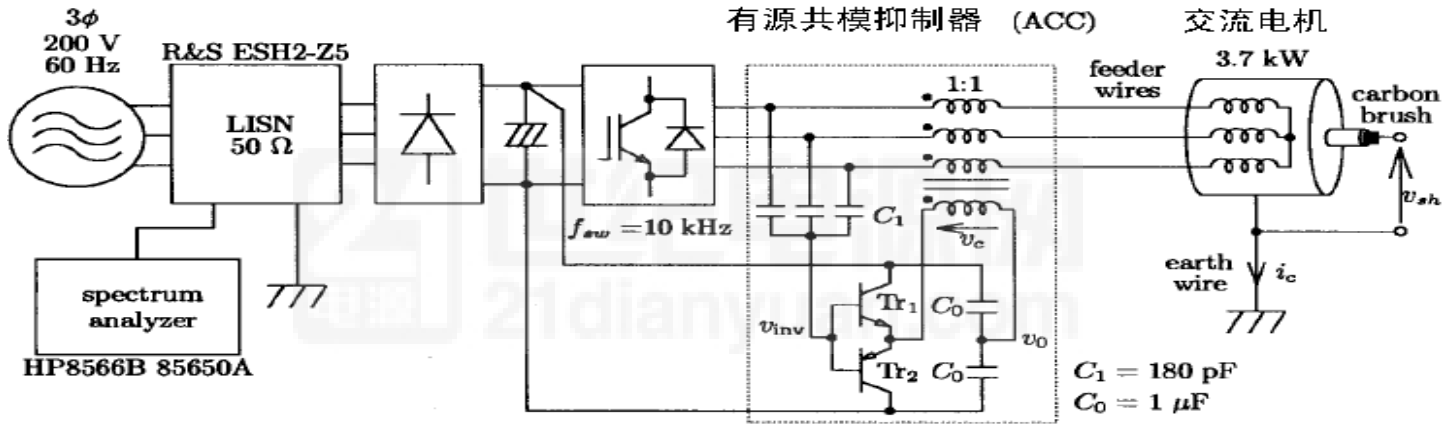
## 电视机电源传导噪声测试实景

# 单相：L，N line




EMI接收机测量上述线上的射频干扰量值，均要小于限值

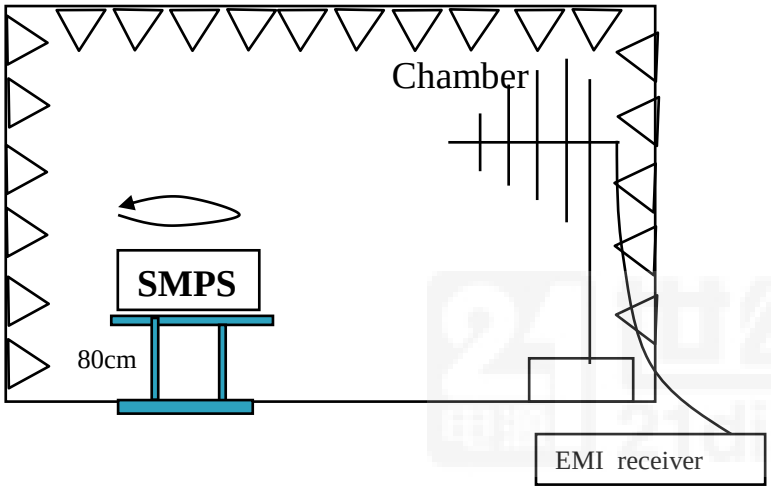
三相：L1，L2，L3，




EMI接收机测量上述线上的射频干扰量值，均要小于限值

# 辐射干扰发射测试

## 测试原理和布局




主要设备

- Antenna：宽带天线
- EUT: 被测设备
- Chamber: 电波暗室
- Turntable：转台
- EMI receiver: 电磁噪声接收机

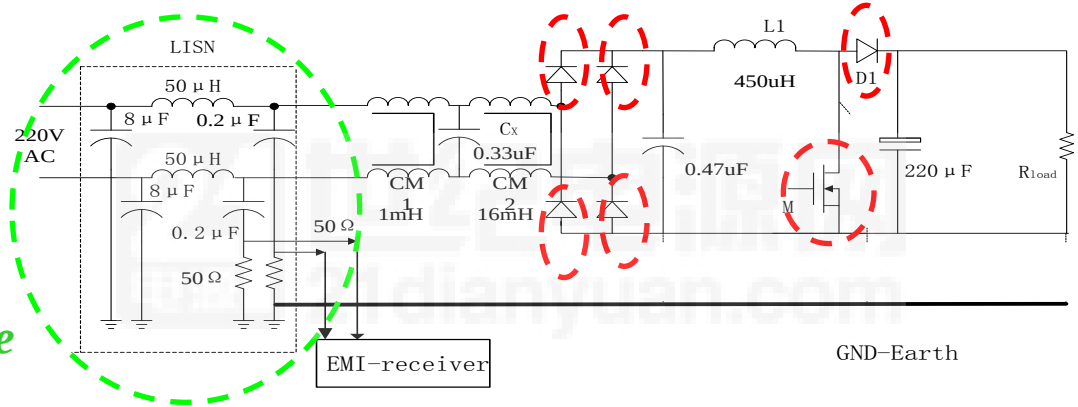
## 3m法辐射测试实景

## 3.1 电力电子装置电磁干扰的产生源头和传播机理

***Three factors of EMI!*** ***EMI source, coupling paths, sensitive objective***

电磁干扰产生的源头

***EMI source***




***Sensitive objective***

***There are lots of different opinions. Mosfet, Diode, transformer, AC loop etc***

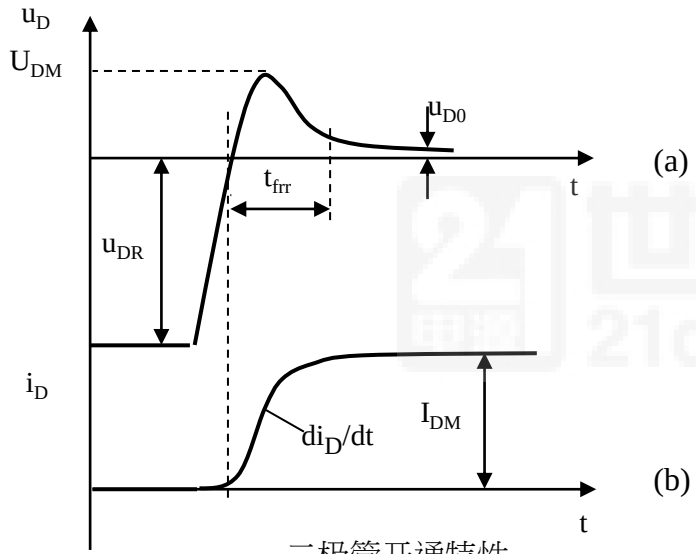
***Strictly speaking,***

***Only Nonlinear switching devices are true EMI sources for EMI emission!***

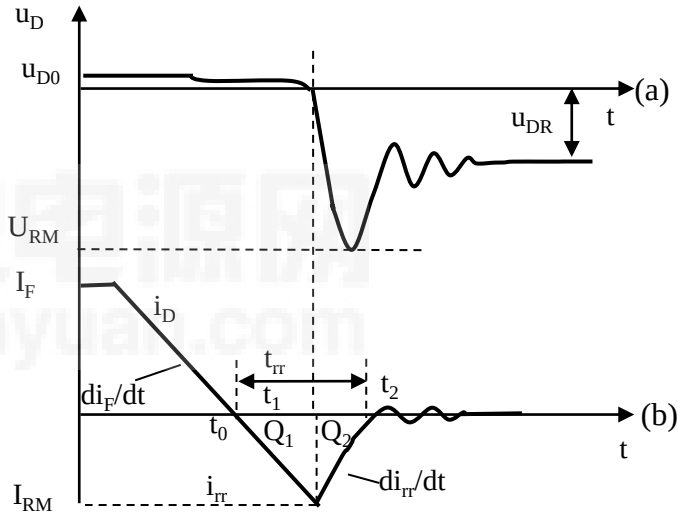
***Others are coupling paths!***

***Only for Radiation emission or simply analysis, others transformer and AC loop can be treated as EMI source!***

# A: Diode turn-on and turn-off

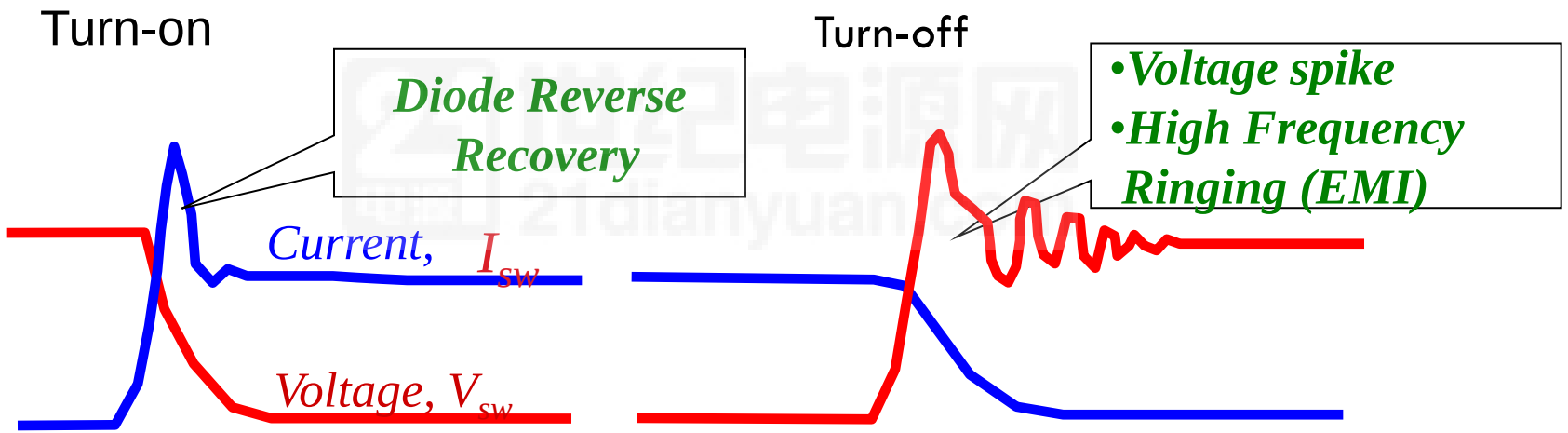



二极管开通特性



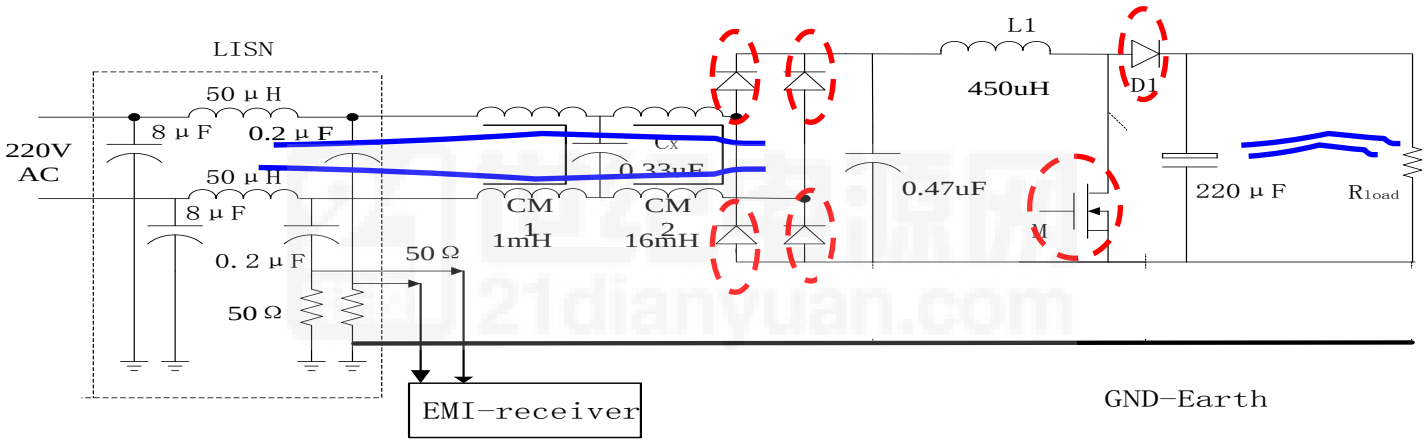

二极管的反向恢复过程（硬恢复）

# B: Transistor turn-on and turn-off



## Basic EMI coupling mechanism

### A: Along metal Lead

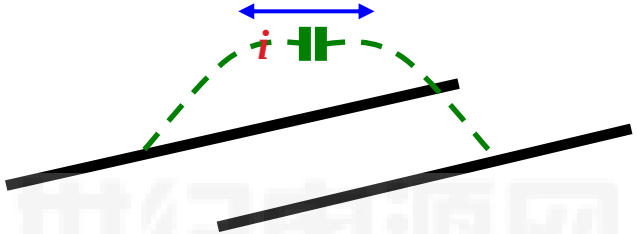


# B: space Induct effect

## B1: Capacitive coupling effect:

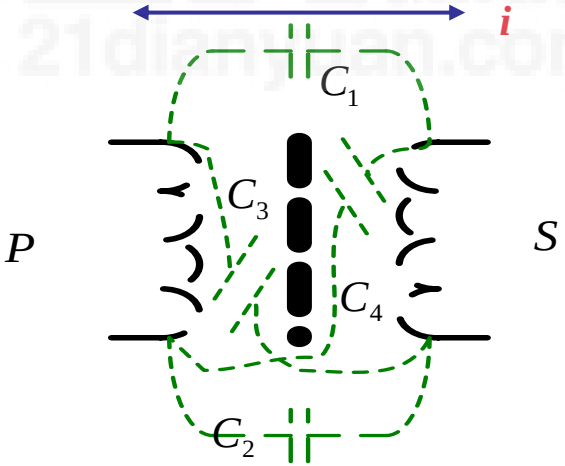
***There is a coupling capacitor between every-two conductors!***

Trace

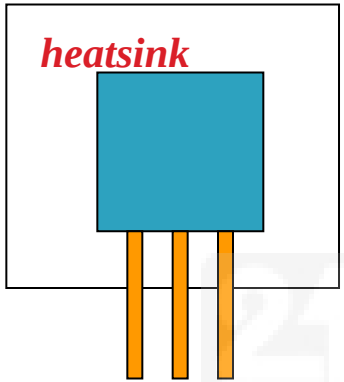


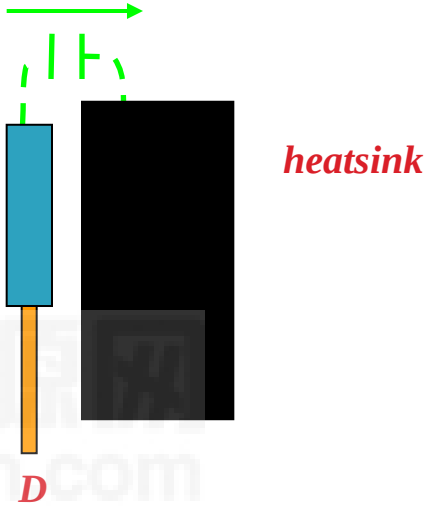

$$C_{12} = k\frac{S_1 S_2}{D}$$

Transformer

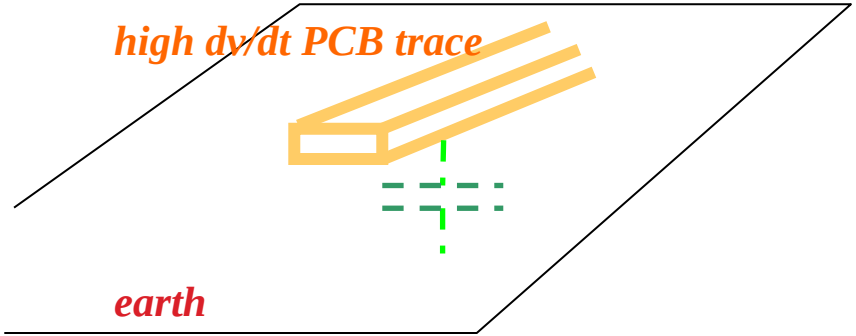


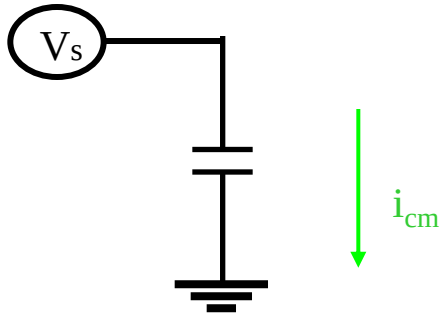
Capacitor between drain to heatsink




Capacitor between high dv/dt trace or metal to earth



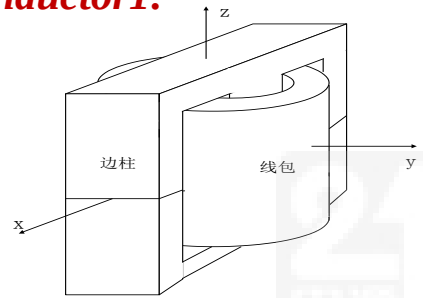



# B2: Inductive coupling effect:

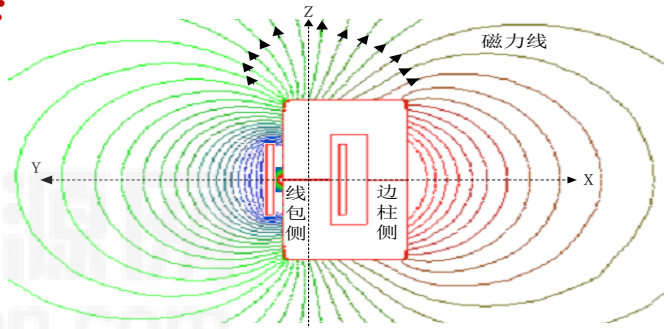
*There is a coupling inductor between every-two loops!*

*Typical magnetic loops:*

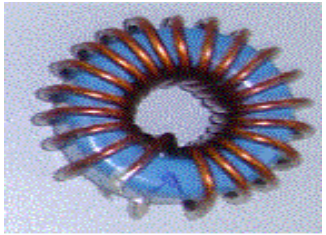
*Inductor1:*

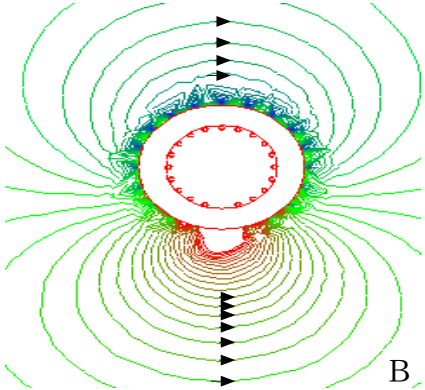



*Transformer:*

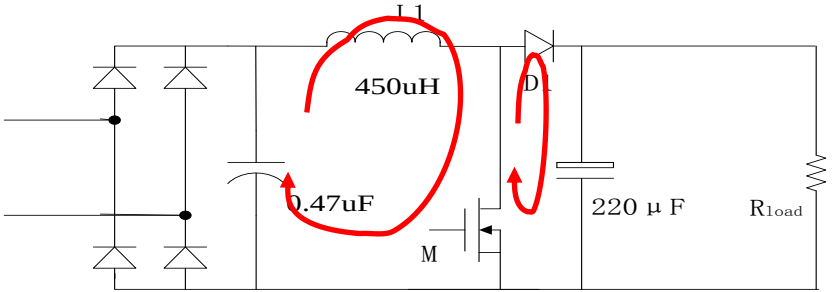


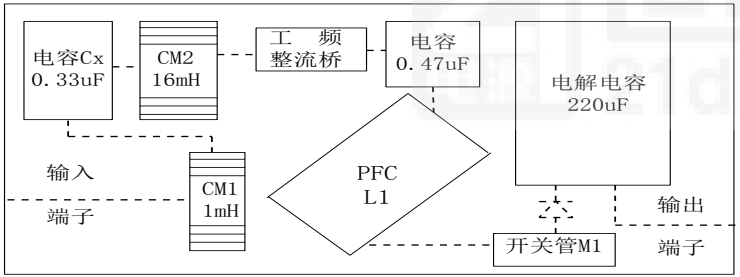

*Inductor2:*

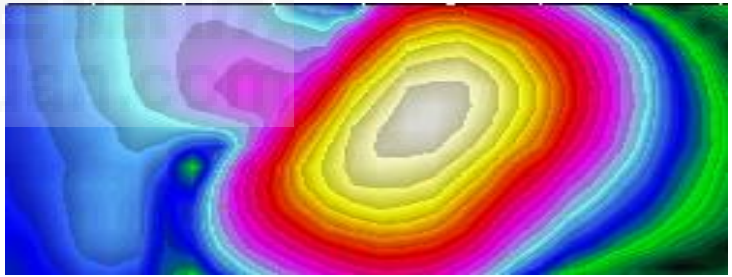




# High frequency AC loops

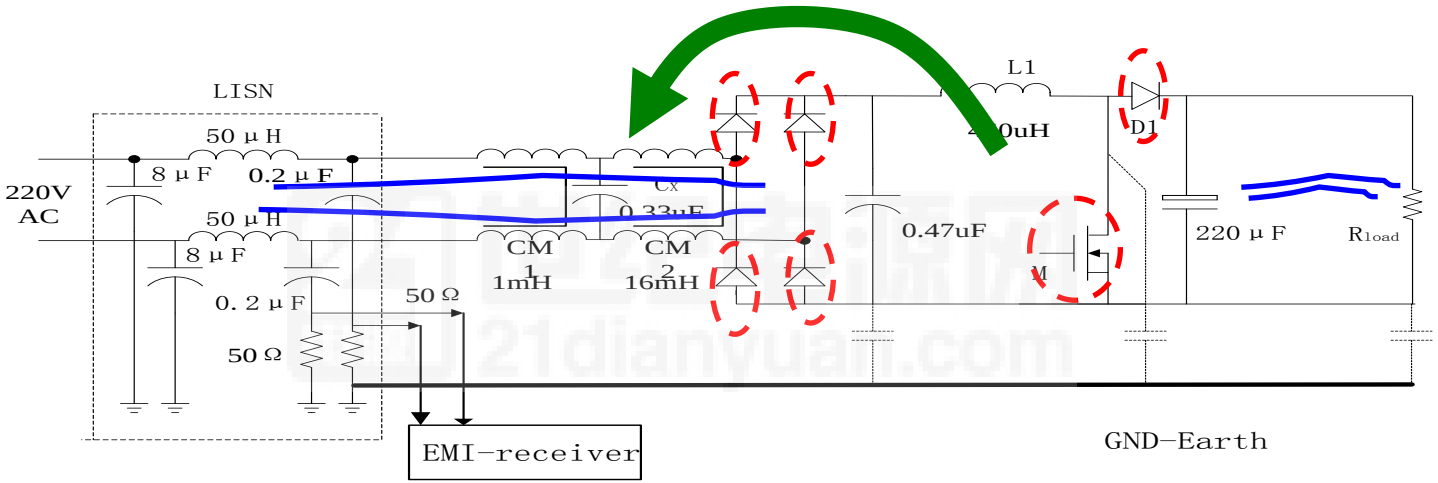


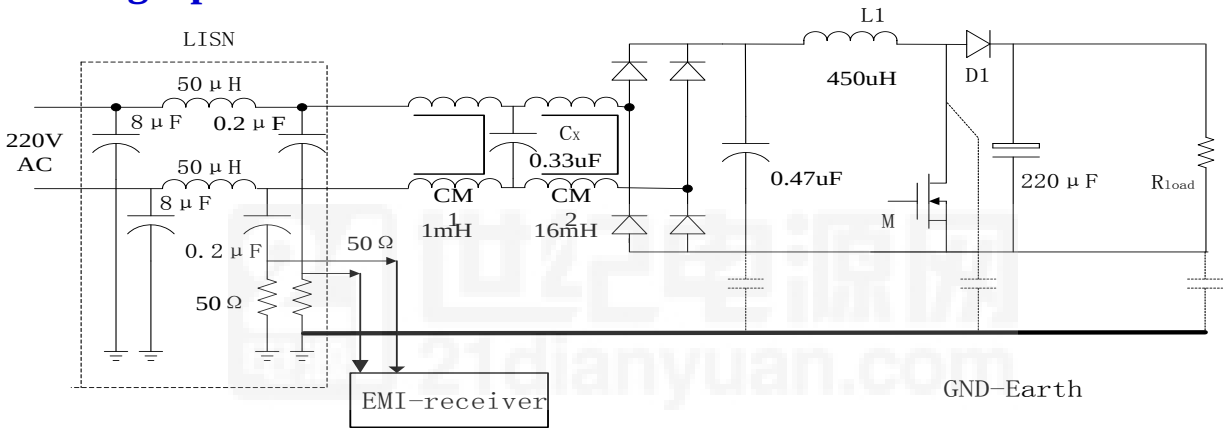
Inductive coupling: produce EMI directly some time ➔sensitive circuit
complicit EMI coupling paths.➔ influence EMI filter performance.

# Total EMI coupling paths



## *Why?*

**Example: Single phase**




Emission on L line: $V_L$

Emission on L line: $V_N$

$$V_{CM} = (V_L + V_N)/2$$
$$V_{DM} = (V_L - V_N)$$

Vcm & Vdm

$$V_L = V_{CM} + V_{DM}/2$$
$$V_N = V_{CM} - V_{DM}/2$$

**So, $V_L$ &$V_N$ $V_{cm}$ & $V_{dm}$ are same!**

因为差模回路和共模回路有不同的特点和性质，分开考虑，便于把握EMI形成、传播和抑制。

差模回路：voltage or current between L&N or among L1、L2、L3

*Through lines-load*

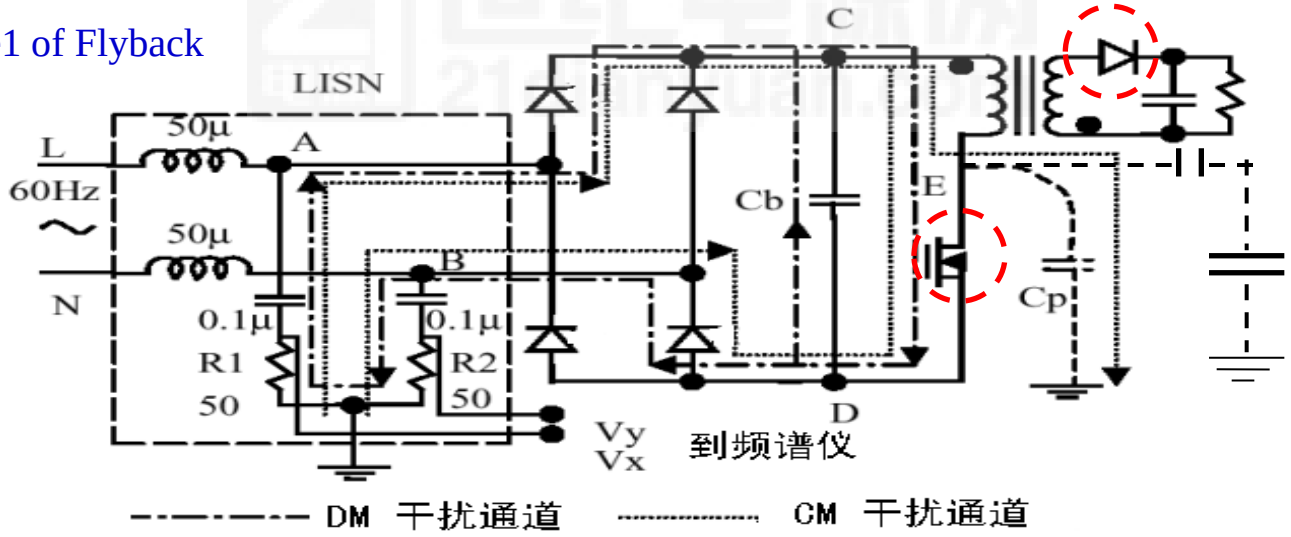
***Equivalent internal impedance is small! Paths is clear!***

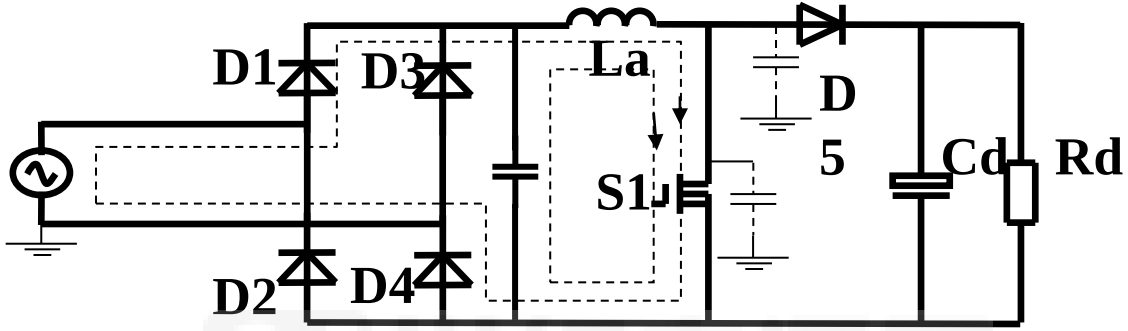
共模回路：voltage or current between lines and Earth

*Through parasitic capacitor*

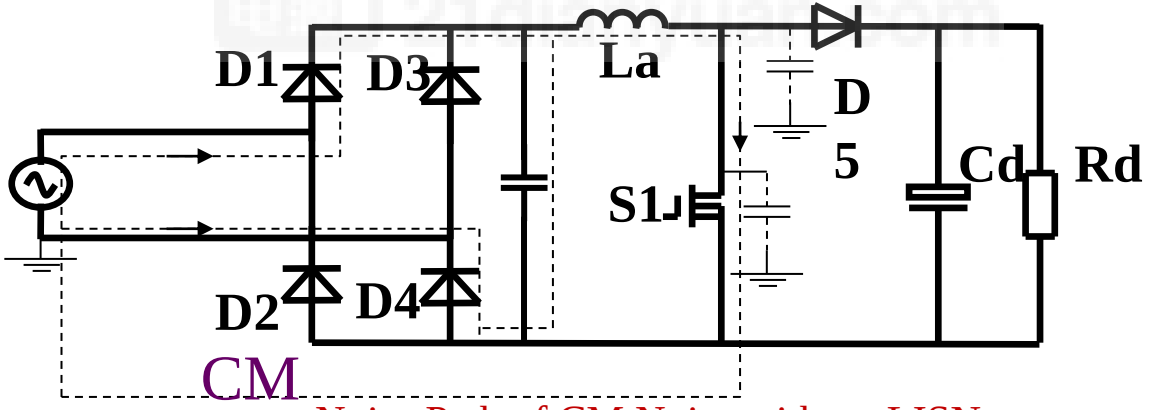
***Equivalent internal impedance is large! Paths is unclear in most case!***

Example1 of Flyback



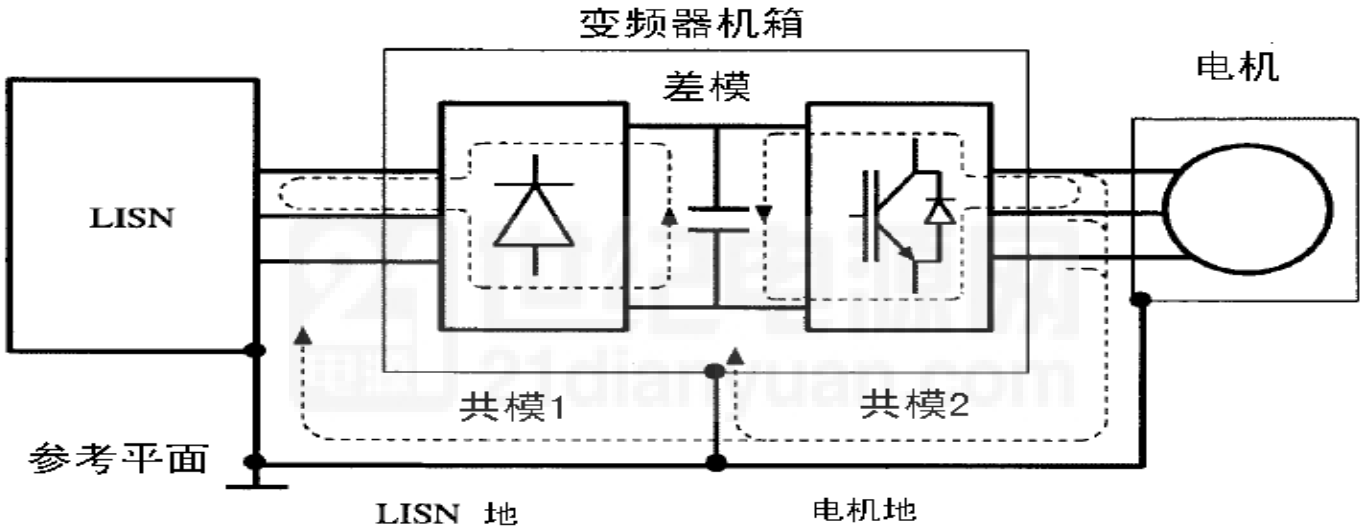



Noise Path of DM Noise without LISN




Noise Path of CM Noise without LISN

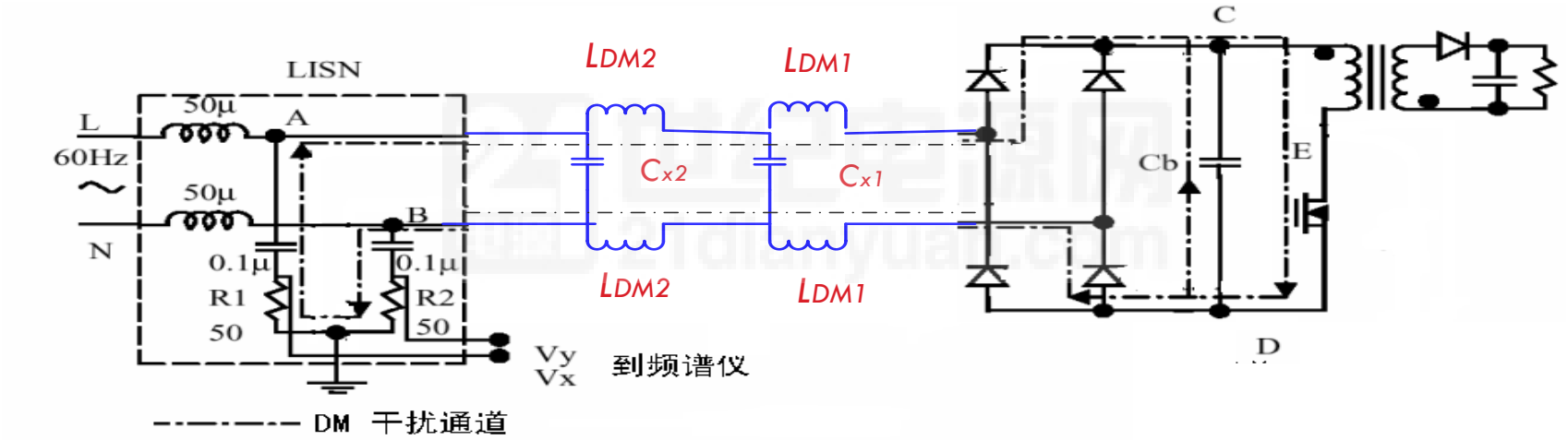
# Example3 of a Driver



# Usage of DM/CM Analysis：

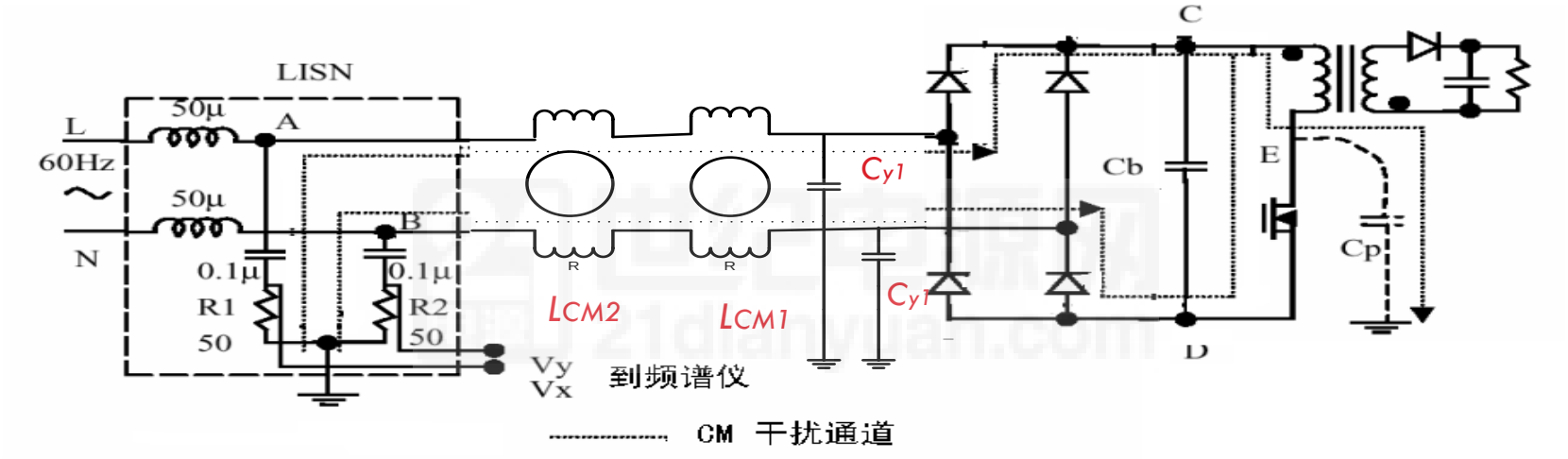
*It is very useful for EMI filter design and EMI debug!*

**DM EMI filter to control DM emission!** It has no influence on CM EMI.



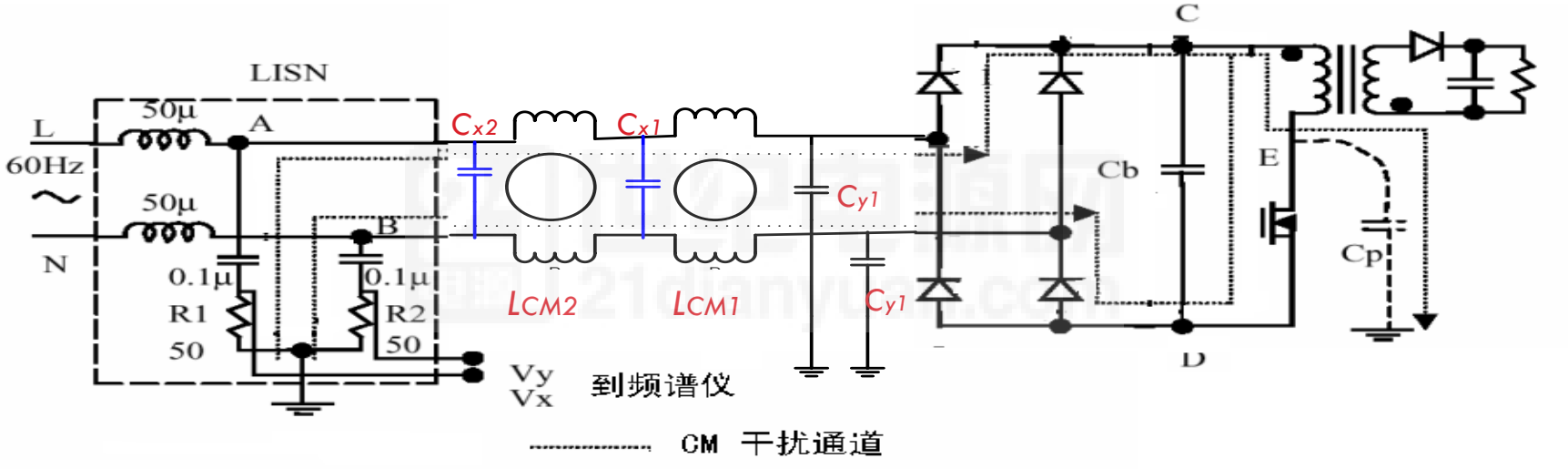

*Generally, Cx is large several uF, Ldm is small!*

**CM EMI filter to control CM emission!** It has no influence on DM EMI.



# An actual EMI filter to control EMI emission!

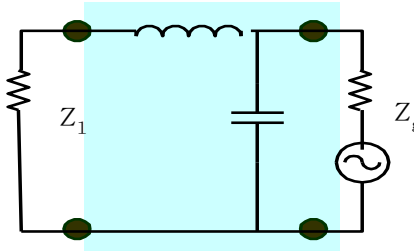
*CM filter+DM filter*

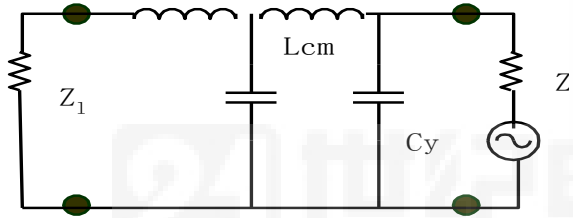


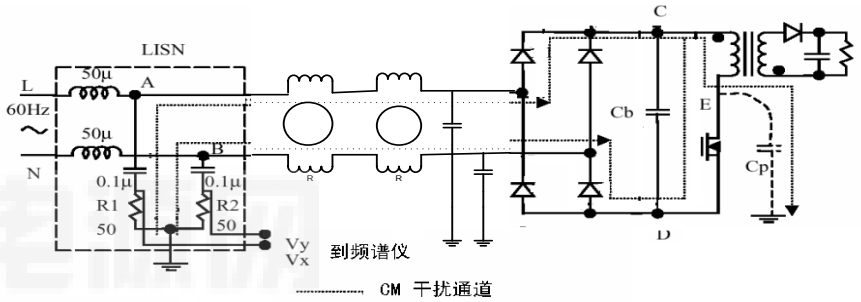

*Caution：The leakage inductance of CM choke can be used as $L_{DM}$*

## 4.1 EMI滤波器的参数设计

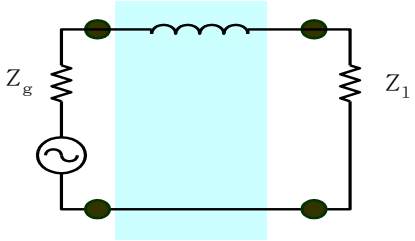
### Multistage CM filter topology

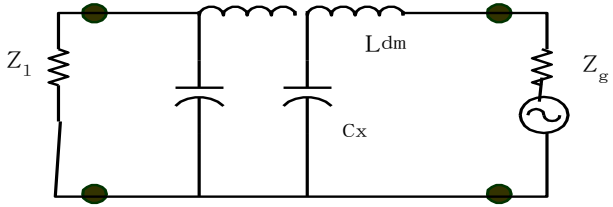


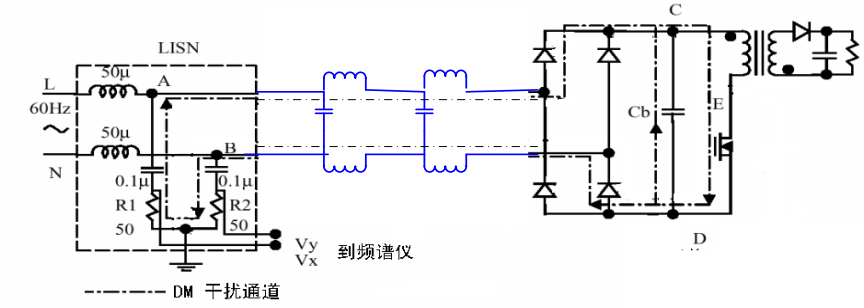



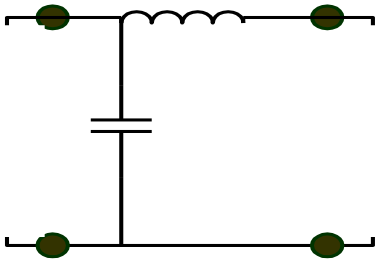



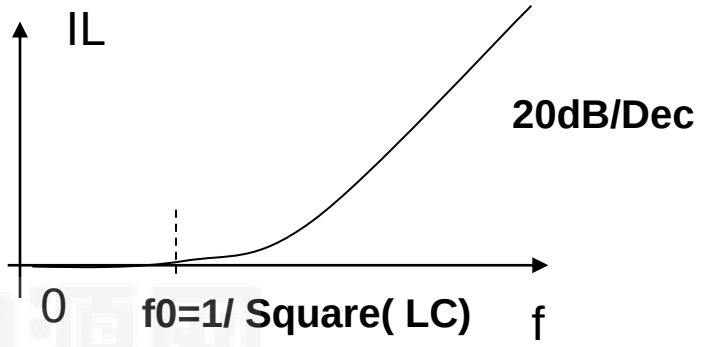

### Multistage DM filter topology



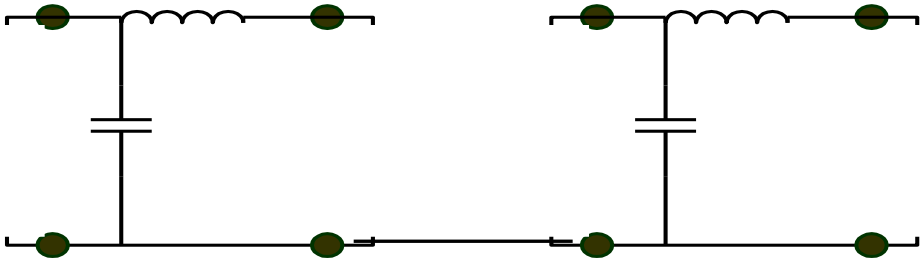



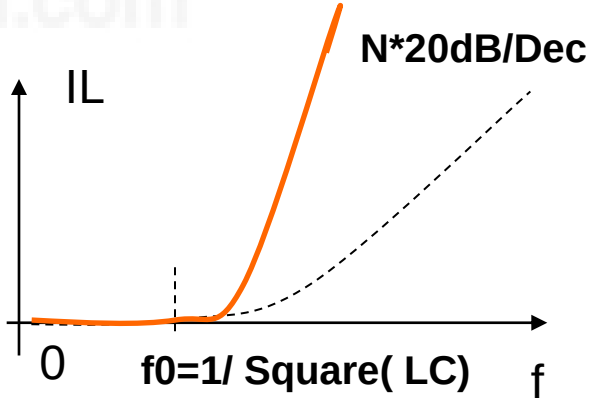







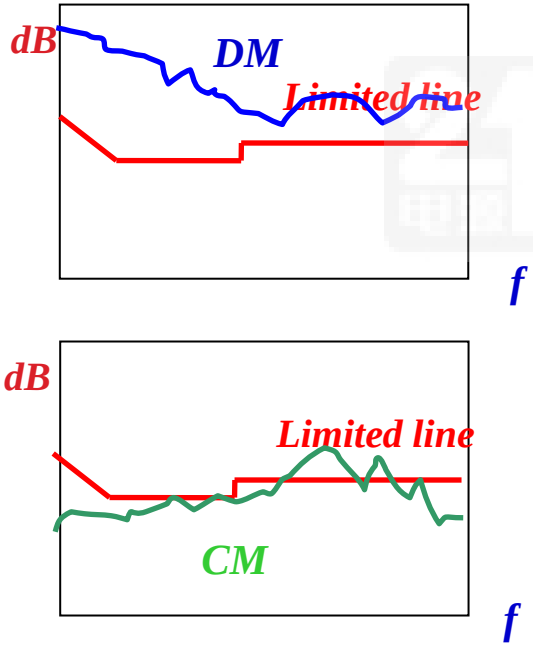

N th



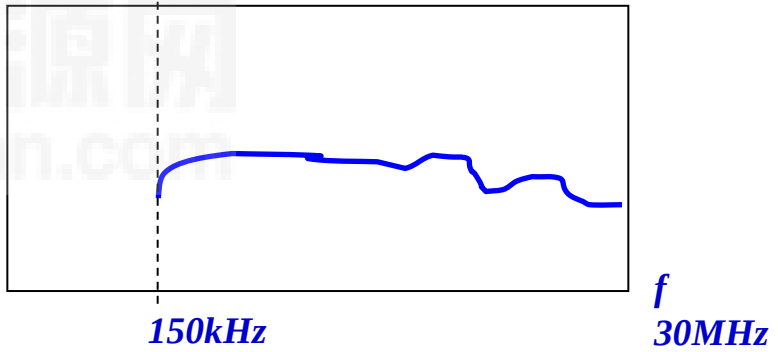


# B: How to decide inductance, capacitance value of EMI filter ?

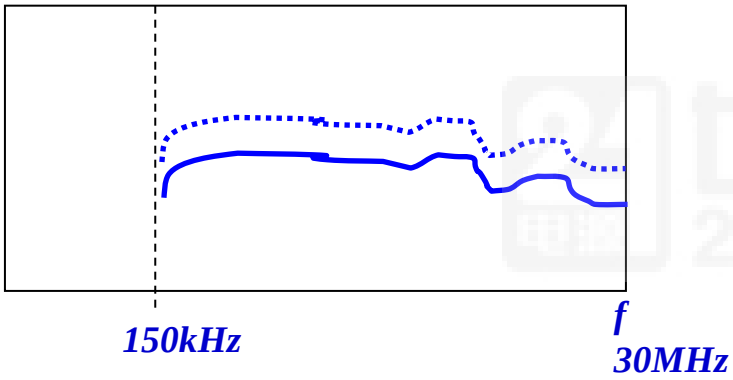
**Step1: Separate CM/DM emission using test or simulation results!**



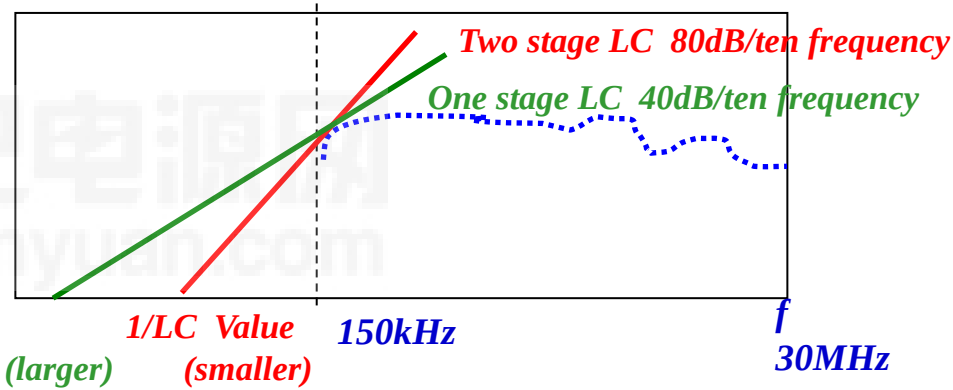

**Step2: Using CM/DM emission decrease limited line, the IL needed of filter are gotten.**



**Step3: adding 10 dB margin for both CM/DM IL needed**

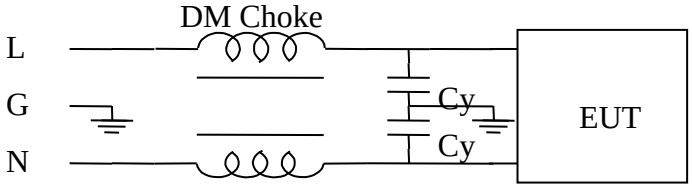



**Step4: According LC number, draw N*40dB line which is tangential to dot IL line.**

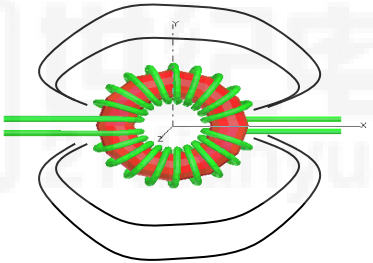


## Step5: LC value, consider other factor, we can decide L and C.

**For CM, the max Cy value is limited by leakage current, so Lcm=f0/Cy. Lcm is called CM choke too.**

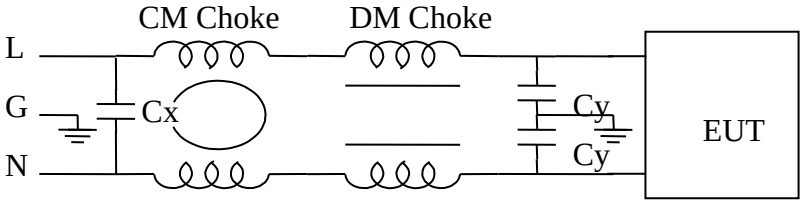



**For DM, for Cx can be easy large enough, Ldm is select small. In most case Ldm can be replaced by the leakage inductor of CM choke.**



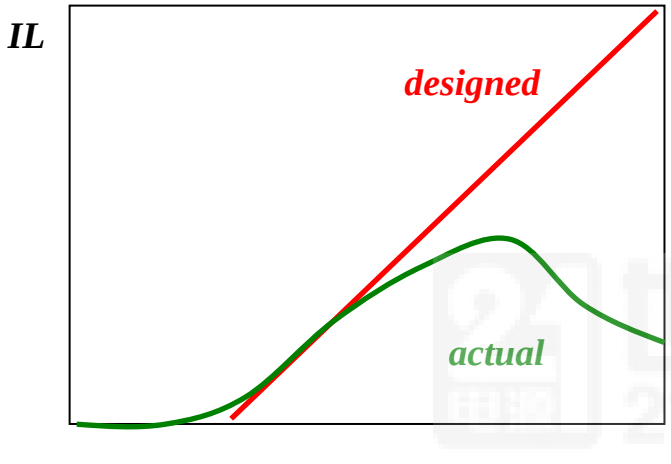
***leakage inductor***

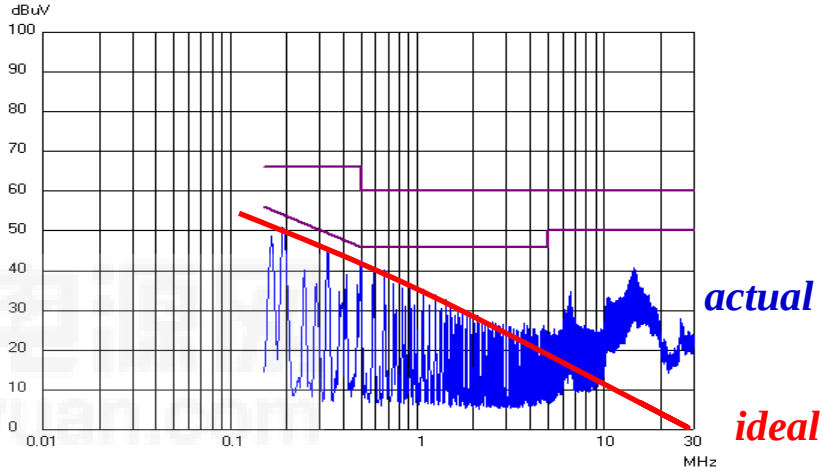
## Step6: finish design and test.

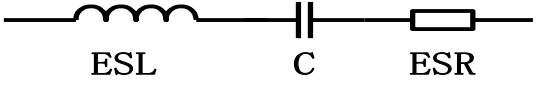


# C: Actual problem after EMI filter inserted

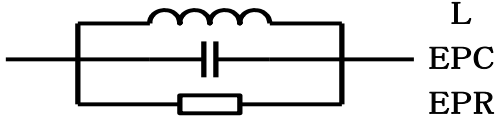
## 1: HF IL are lower than expected.




Capacitor Model




Inductor Model

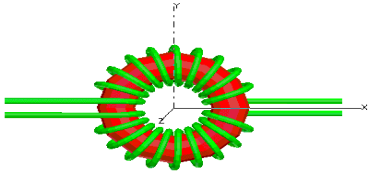
# What to do?

Decrease parasitic as possible!

1: Using good HF capacitor or inductor! Small parasitic parameter!

对于电感：

铁氧体：易饱和、导磁率高，常用作共模扼流圈的磁芯



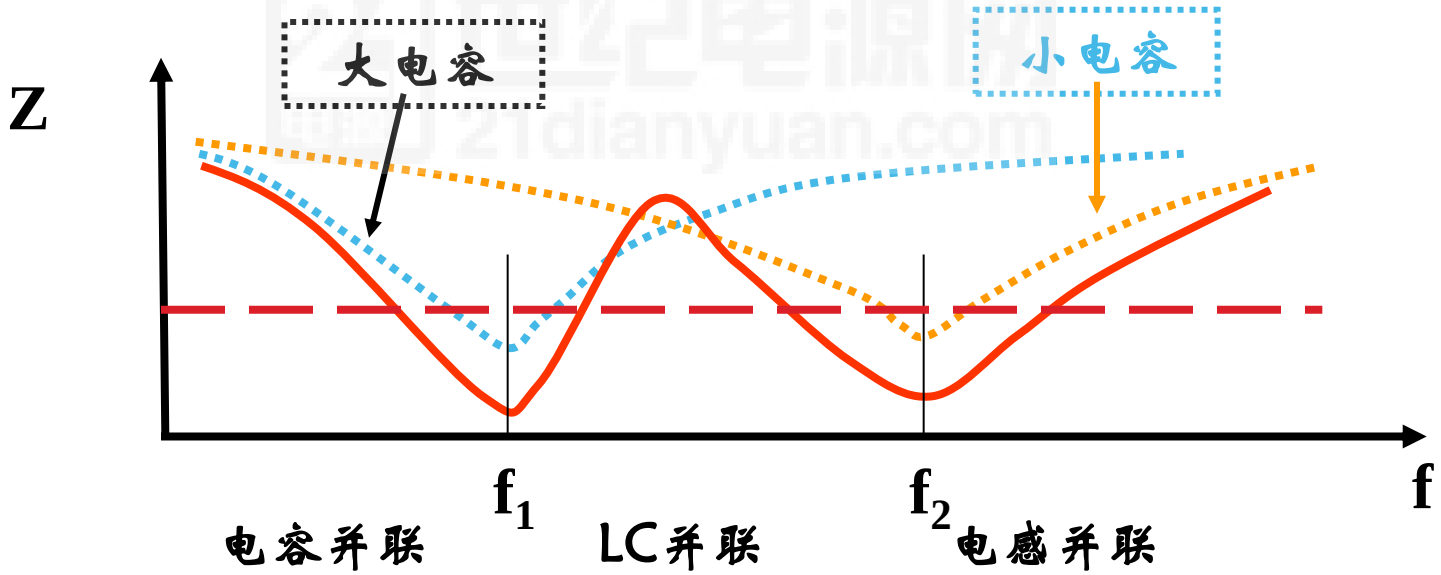
锰锌：μr = 500～10000 for lower frequency CM choke

镍锌：μr = 10～100 fit for HF CM choke

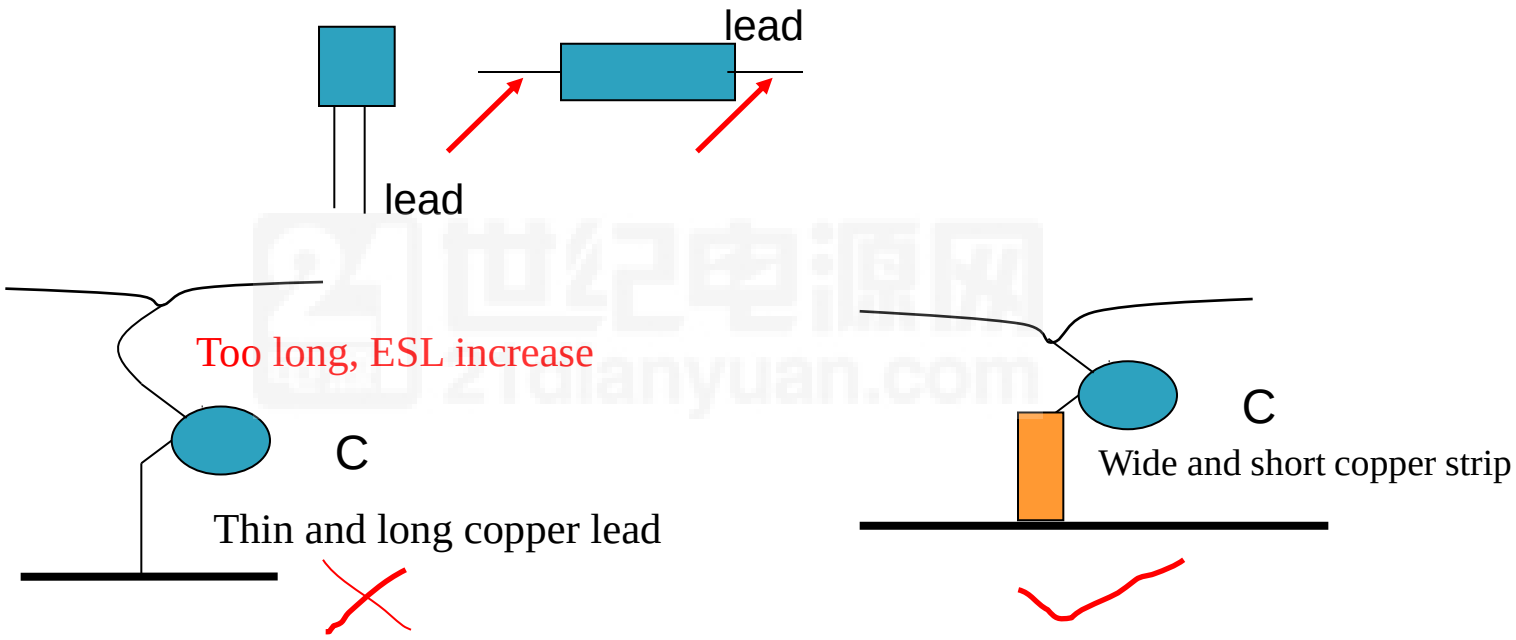
采用少匝，交错绕制等办法减小线圈的EPC！

对于电容

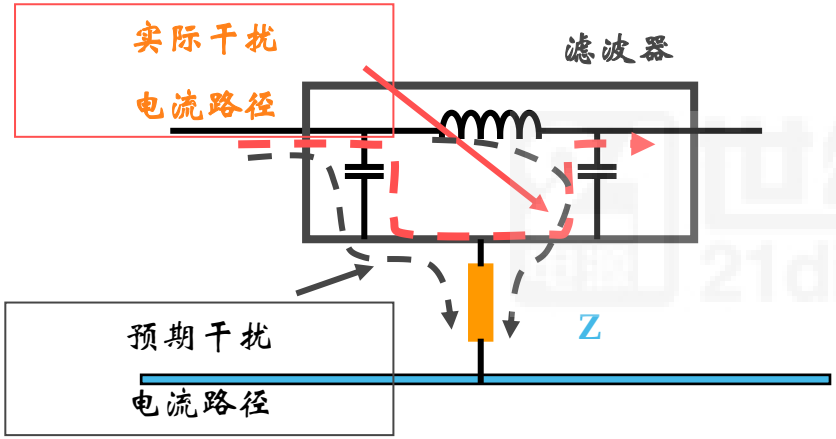
**1：采用高频性能好的小电容。**

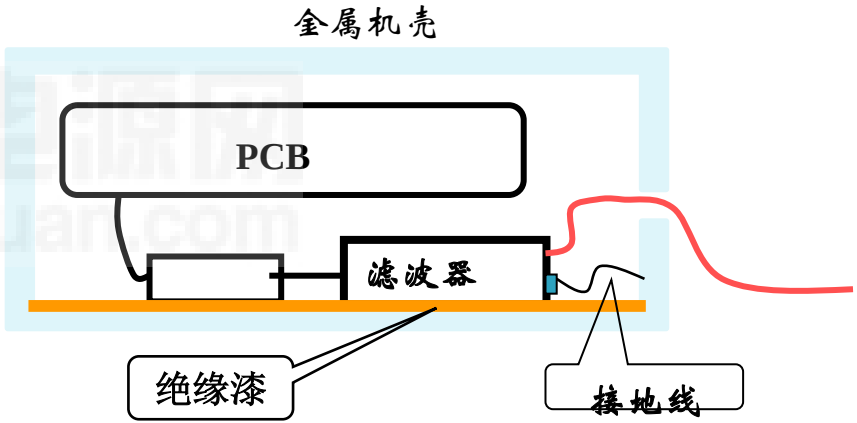



## 2: Decrease lead length of capacitor as shorter as possible. ESL!

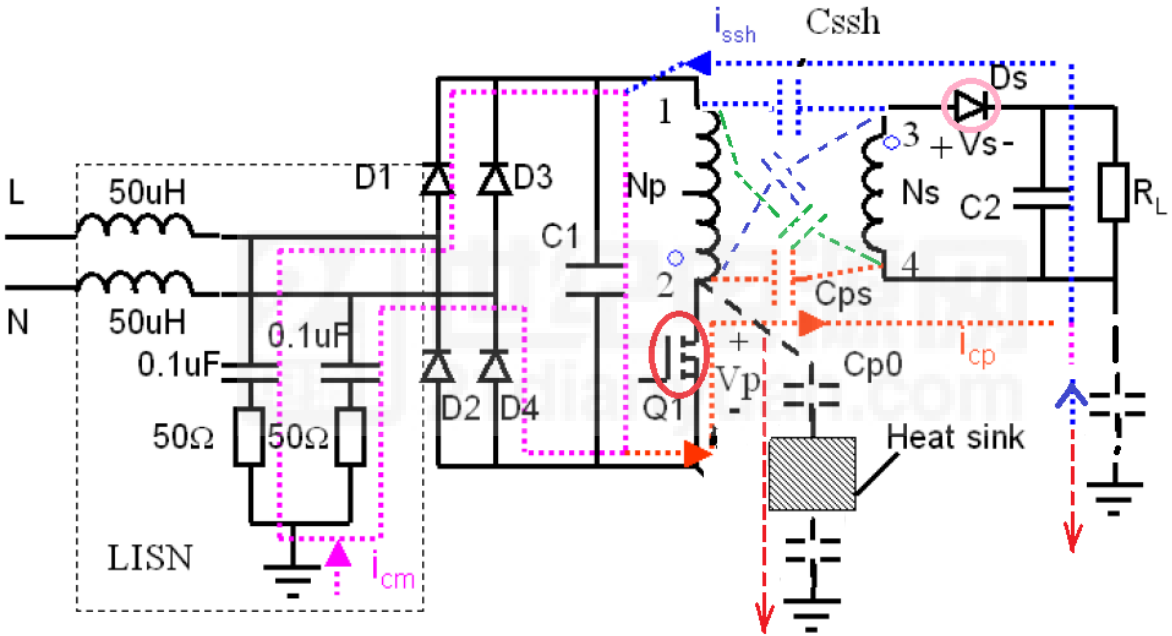


# 3: Carefully installment!



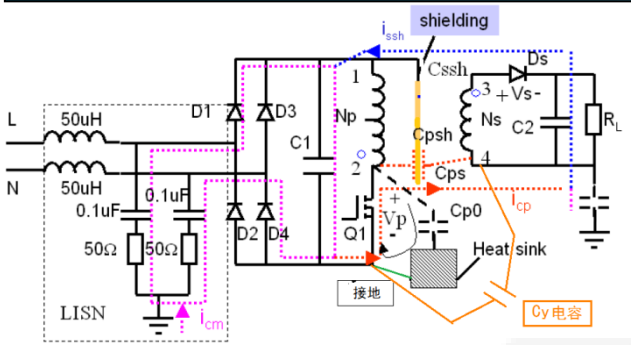



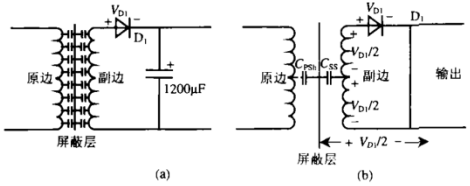
Flyback电源为例

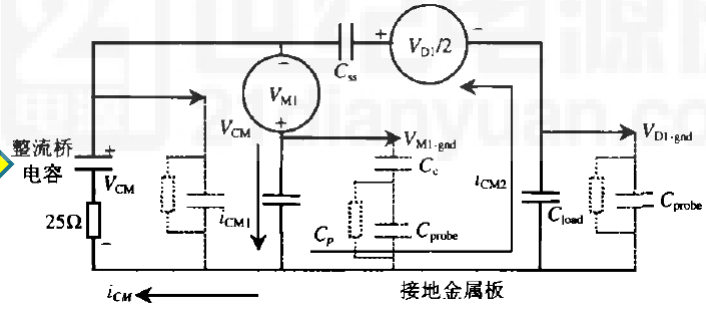


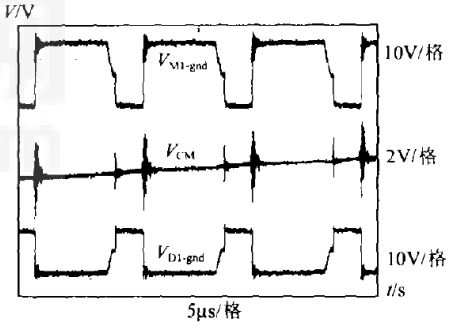

原始噪声通道 **Vp » Vd**

# 原副边抵消作用



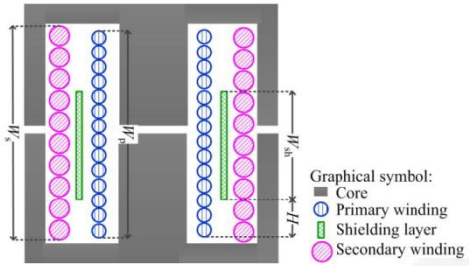



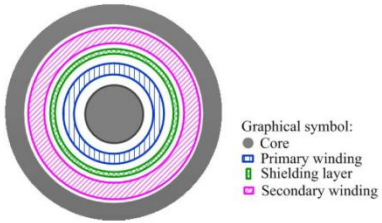



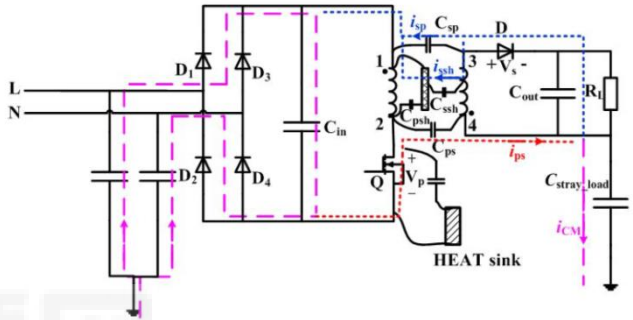

Icp=issh

屏蔽后变压器简化模型

## 2：变压器屏蔽层居中结构设计




2016, Henglin Chen

$$i_{ps} = f_{11}(H, W_{sh}, C_{ps0})$$

$$i_{ssh} = f_2(H, W_{sh})$$

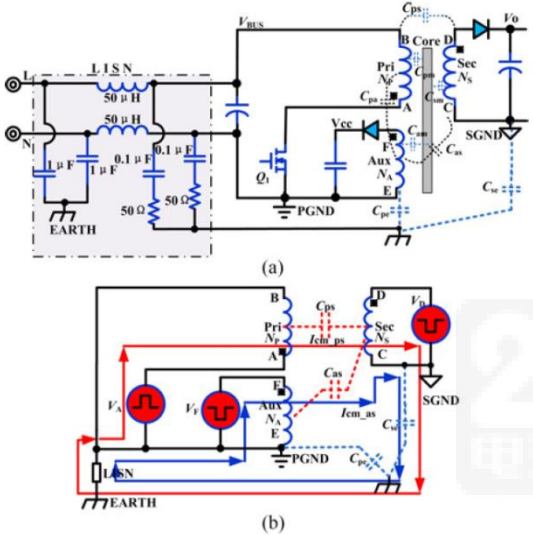
$$i_{sp} = f_3(H, W_{sh})$$

$$i_{CM} = i_{ps} - (i_{sp} + i_{ssh}) = 0$$

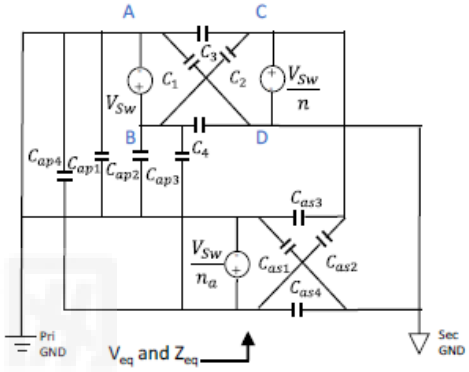
优点：低成本。低漏电流。

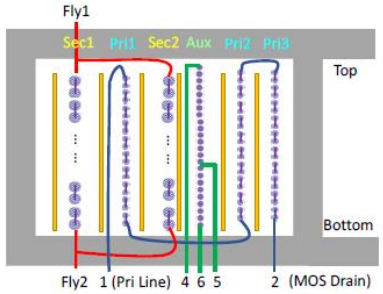
缺点：绕制工艺要控制

## 3：类似具体工程设计




2017, Yongjiang Bai




2017, Yiming Li

## Modern modulation techniques

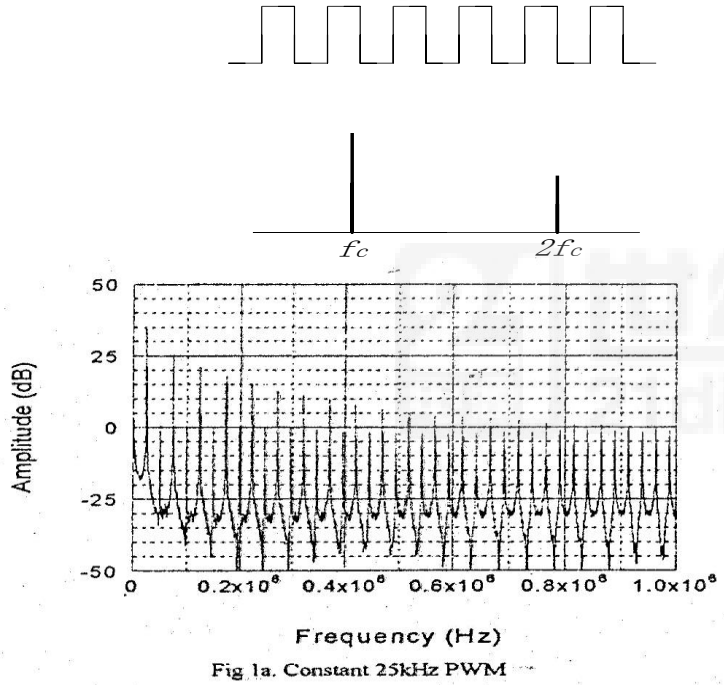



Fig 1a. Constant 25kHz PWM

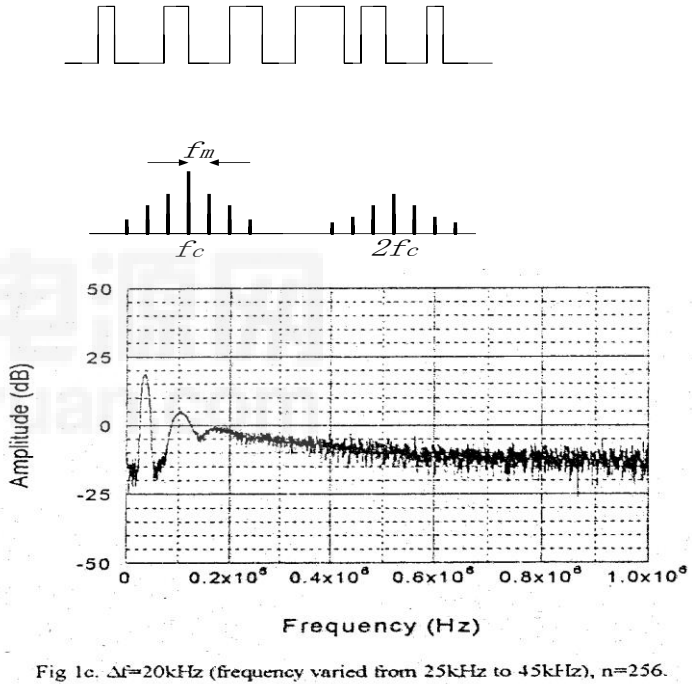



Fig 1c. Δf=20kHz (frequency varied from 25kHz to 45kHz), n=256.

***Switching frequency modulation***

*__ proposed by F. Lin et al , IEEE PESC'93*

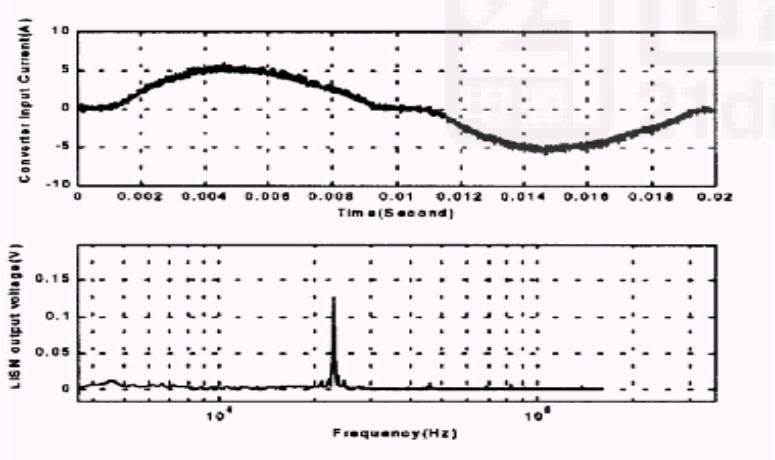
- ***Random modulation***

_____ *proposed by D.A. Stone et al, IEEE APEC'96*

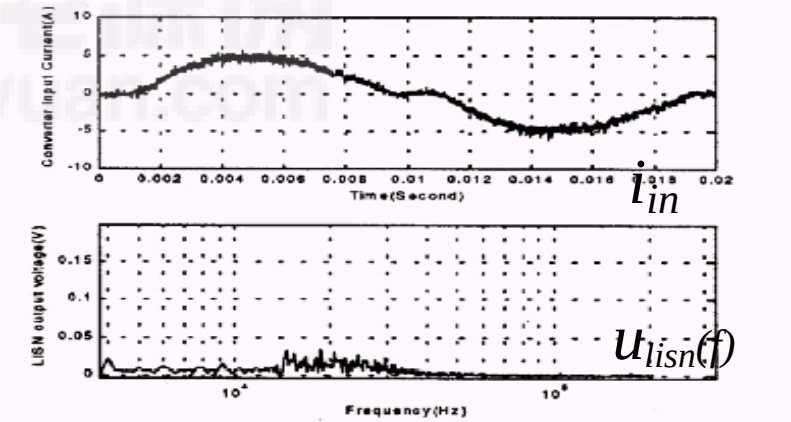
- ***Sigma - Delta modulation***

_____ *proposed by J. Paramesh et al, IEEE APEC'99*

- ***Comparison : PWM & RPWM***

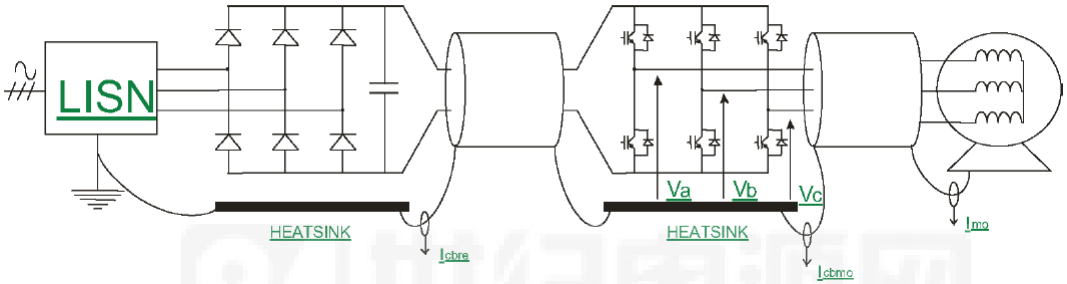


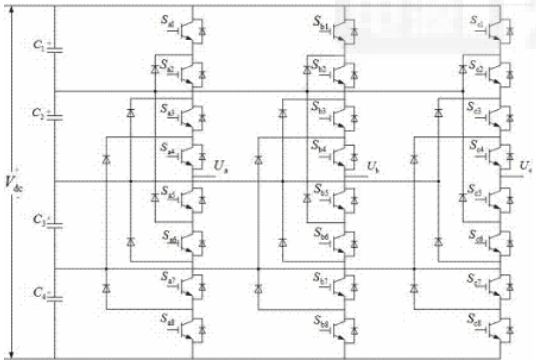

PWM, f = 25 kHz

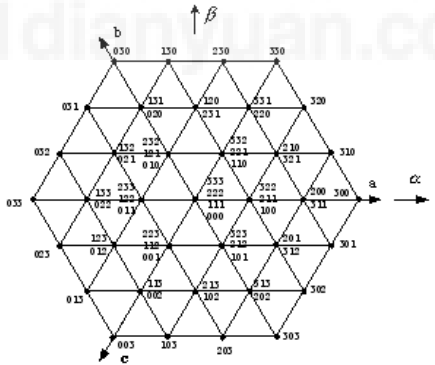


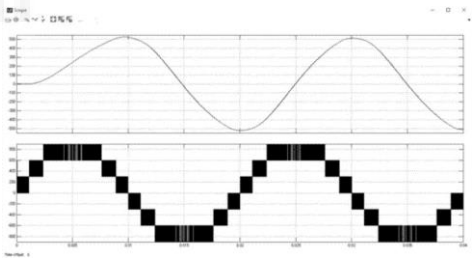

RPWM, 15 kHz< f <30 kHz

# *Jitter and PWM modulation fit for SMPS, inverter, multilevel converter*





# 五：总结

1： 详细介绍了开关电源电磁干扰的产生原理、差/共模通道及几种典型电源的干扰模型；

2： 细致介绍了EMI滤波器设计、无Y电容电源设计、抖频调制等实用新型抑制和设计技术；

3: 介绍和探讨了开关电源EMC设计挑战和机遇。

# 问答和讨论环节

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# 谢谢大家！

***Thanks for your attention!***